April 5, 2001
HETA 2001-0090

John Stenseth
General Manager
9801 South Grant
Rural Route 4
Muncie, Indiana 47302

Dear Mr. Stenseth:

On December 1, 2000, the National Institute for Occupational Safety and Health (NIOSH) received a request from management officials of Fun Country Marine Industries Inc. to evaluate carbon monoxide (CO) concentrations associated with the operation of houseboats on Lake Mead. On January 23 - 24, 2001, NIOSH investigators visited Lake Mead to investigate CO concentrations on houseboats located at Callville, Nevada. This letter describes our evaluation methods, findings, and conclusions.

Background

Previous investigations were performed by NIOSH industrial hygienists and representatives from several agencies in September 2000 and October 2000 in response to CO related poisonings and deaths on houseboats at Lake Powell, Arizona. These investigations characterized the circumstances of boat related CO poisonings through review of emergency medical service (EMS) transport records, and measured hazardous CO concentrations on houseboats.[1,2] Incident reports provided by the National Park Service revealed 9 known boat-related CO poisoning deaths on Lake Powell since 1994. Some of these incidents involved multiple poisonings in addition to the deaths reported (total of 15 people poisoned in the 8 incidents involving fatalities). Information regarding the fatalities is presented in a previous report.[1] An additional evaluation conducted in October, 2000 at Lake Cumberland also revealed hazardous CO concentrations around the swim platform on houseboats with gasoline powered generators/motors.[3]

Some of the severely hazardous situations identified during the September and October 2000 evaluations at Lake Powell and Lake Cumberland included:

- The open space under the swim platform could be lethal under certain circumstances (i.e., generator/motor exhaust discharging into this area) on some houseboats.

- Some CO concentrations above and around the swim platform were at or above the immediately dangerous to life and health (IDLH) level (greater than 1,200 parts of CO per million parts of air [ppm]).
- At Lake Powell, measurements of personal CO exposure during boat maintenance activities indicated that employees may be exposed to hazardous concentrations of CO. (Personal monitoring on workers at Lake Cumberland was not conducted)

Please refer to Attachments 1 and 2 for discussions of health effects of CO exposure and relevant evaluation criteria.

Methods and Materials

The environment near the generator exhaust discharge was characterized using a KAL Equip Model 5000 Four Gas Emissions Analyzer (KAL Equip, Cleveland, Ohio). This analyzer measures CO, carbon dioxide (CO_2), hydrocarbons, and oxygen. CO and O_2 measurements are expressed as percentages. (One percent of contaminant is equivalent to 10,000 ppm.) Air contaminants in the area near the generator exhaust were determined when only the generator was operating, and when the generator and boat engines were operating simultaneously.

CO concentrations were measured on the back of the houseboats using ToxiUltra Atmospheric Monitors (Biometrics, Inc., Middletown, Connecticut) with CO sensors. All ToxiUltra CO monitors were calibrated before and after each use according to the manufacturer's recommendations. These monitors are direct-reading instruments with data logging capabilities. The instruments were operated in the passive diffusion mode, with a 30 second sampling interval. The instruments have a nominal range from 0 ppm to 500 ppm with the highest accurate instantaneous reading of 1000 ppm. Figure 1 illustrates a typical houseboat and where ToxiUltra CO monitors were placed. Some of the locations varied on different houseboats depending on the swim deck and swim platform designs.

CO measurements were also made with detector tubes (Drager CO, CH 29901– range 0.3% [3,000 ppm] to 7% [70,000 ppm], and Drager CO, CH 25601-range 100 - 700 ppm) in the areas near the exhaust and around the swim deck. The detector tubes are used by drawing air through the tube with a bellows–type pump. The resulting length of the stain in the tube (produced by a chemical reaction with the sorbent) is proportional to the concentration of the air contaminant.

"Grab" samples were collected using Mine Safety and Health Administration (MSHA) 50–milliliters (mL) glass evacuated containers. These samples were collected by snapping open the top of the evacuated glass container and allowing the air to enter. The containers were sealed with wax–impregnated MSHA caps. The samples were then sent by overnight delivery to the MSHA laboratory in Pittsburgh, Pennsylvania where they were analyzed for CO using a HP6890 gas chromatograph equipped with dual columns (molecular sieve and porapak) and thermal conductivity detectors.

Results

67 foot VIP Houseboat

During the morning on January 23, 2001, CO samples were collected on a 67' VIP model houseboat with the specifications listed below. During this evaluation, the gasoline generator operated alone for approximately 34 minutes. Subsequently, the gasoline motors and generator were operated together for approximately 26 minutes.

Engines: Two Evinrude Ficht® outboard marine corporation (OMC), 150 HP, engines
Generator: 15 Kw Kohler, 4 cylinder, 1800 RPM, gasoline generator
Exhaust Configuration: Generator exhaust discharged out to the side of the houseboat.
Wind speed above deck: air speed readings ranged between 131 - 256 feet per minute
Wind speed at side of deck near generator exhaust: air speed readings ranged between 10 - 119 feet per minute

Area around exhaust and off back of houseboat

Figure 2 shows a portion of the back deck of the VIP houseboat, and illustrates the generator exhaust discharging out the side. Two evacuated glass container samples were collected in the area near the generator exhaust discharge. These two samples indicated CO concentrations of 3460 and 7071 ppm. Another evacuated container sample was collected directly off the back of the boat approximately 8 inches above the water. This sample indicated a CO concentration of 896 ppm.

The emissions analyzer sampling probe was placed near the generator exhaust discharge of the houseboat. A total of 21 readings were obtained (over a 34 minute period) when only the generator was in operation. The recorded CO concentration ranged from 0% (0 ppm) to 2.4 % (24,000 ppm) with an average of 0.58 % (5,800 ppm). A total of 19 CO concentration readings were obtained near the generator exhaust discharge when the generator and engines were both in operation. These CO concentrations ranged from 0.0 % (0 ppm) to 1.1 % (11,000 ppm) with an average of 0.5 % (5,000 ppm). During brief periods, when the CO concentrations were high, the emissions analyzer would also indicate that the area directly around the exhaust discharge was oxygen deficient (< 19.5 % O_2).

Detector tube samples collected in the area around the generator exhaust indicated CO concentrations of 3,000 ppm while the generator was in operation and 5,000 ppm when the generator and motors were in operation.

Area Above Swim Deck on Back of Boat

The prevailing wind direction was moving from the right side of the back deck (when on back of boat and facing the water) and flowing across the back deck toward the left side. Table 1 lists the CO monitor results obtained on the back of the 67' VIP houseboat.

Table 1. Sample locations and CO results on the 67' VIP houseboat.

Location	**CO average (ppm)**	**CO peak (ppm)**
Only Gasoline Generator Running (ran for approximately 34 minutes without motors operating)		
On the back of the slide at breathing zone height	70	101
Right of back deck (when on boat and facing the water) at floor level	55	761
Left of back deck (when on boat and facing the water) at floor level	116	168
Center of back deck at floor level	153	224
On the left side of the rear portion of the back deck (approximately 3 feet off the deck floor)	276	388
On stairs going up to top deck (at breathing zone height)	33	270
On the top deck of boat	35	53
Inside the boat	37	53
Gasoline Generator and Gasoline powered Outboard Motors Running (ran together for approximately 26 minutes)		
On the back of the slide at breathing zone height	39	50
Right of back deck (when on boat and facing the water) at floor level	0.2	2
Left of back deck (when on boat and facing the water) at floor level	76	94
Center of back deck at floor level	105	129

Gasoline Generator and Gasoline powered Outboard Motors Running (ran together for approximately 26 minutes)		
On the left side of the rear portion of the back deck (approximately 3 feet off the deck floor)	169	209
On stairs going up to top deck (at breathing zone height)	3	11
On the top deck of boat	21	26
Inside the boat	29	35

65' VIP Houseboat

During the mid-morning on January 23, 2001, CO samples were collected on a 65' VIP houseboat with the specifications listed below. During this evaluation, the gasoline generator operated alone for approximately 30 minutes. Subsequently, the gasoline motors and generator were operated together for approximately 21 minutes.

Engines: Two Volvo, 3.0 liter gasoline I/O, 130 HP engines
Generator: 12.5 Kw Kohler, 4 cylinder, 1.3 liter gasoline generator
Exhaust Configuration: Generator exhaust out the back of the boat.
Air speed above deck: air speed readings ranged between 15 - 130 feet per minute
Air speed off back of back deck (near water): air speed readings ranged between 0 - 109 feet per minute

Area around exhaust off back of houseboat

An evacuated glass container sample was collected in the area near the generator exhaust discharge at the back of the houseboat when the generator was in operation (motors were not operating). This sample indicated a CO concentration of 1437 ppm. Two additional evacuated container samples were collected at different times near the ladder which leads down to the water off the back of the boat. These samples indicated CO concentrations of 433 and 5 ppm when only the generator was in operation. A detector tube collected at this location (near the ladder which leads down to the water) indicated a CO concentration of 300 ppm.

An evacuated container sample was collected while the generator and motors were in operation near the ladder off the back of the swim platform approximately 12 inches above the water. This sample indicated a CO concentration of 629 ppm. A detector tube collected near the generator exhaust (while the generator and motors were in operation) indicated a CO concentration of 5,000 ppm.

The emissions analyzer sampling probe was placed near the generator exhaust discharge. A total of 14 readings were obtained (over a 24 minute period) when only the generator was in operation. The recorded CO concentration (obtained near the exhaust discharge) ranged from 0% (0 ppm) to 0.59 % (5,900 ppm) with an average of 0.27 % (2,700 ppm). A total of 13 CO readings were obtained near the generator exhaust when the generator and engines were both in operation. These CO concentrations ranged from 0.01 % (100 ppm) to 1.28 % (12,800 ppm) with an average of 0.65 % (6,500 ppm). During brief periods, when the CO concentrations were high, the emissions analyzer would also indicate that the area directly around the exhaust discharge was oxygen deficient (< 19.5 % O_2).

Area Above Swim Deck on Back of Boat

The prevailing wind direction was toward the back left corner of the rear deck (when on back of boat and facing the water) and flowing across the back deck. Table 2 lists the CO monitor results.

Table 2. Sample locations and CO results on the 65' VIP Houseboat.

Location	**CO average (ppm)**	**CO peak (ppm)**
Only Generator Running (ran for approximately 30 minutes without motors operating)		
On the back of the slide at breathing zone height	58	122
Right side of the back deck (at floor level)	149	171
Left side of the back deck (at floor level)	515	1292*
Middle of the back deck	69	215
On stairs going up to top deck	35	137
On the top deck of boat	7	9
Inside the boat	1	3
Generator and Motors Running (ran together for approximately 21 minutes)		
On the back of the slide at breathing zone height	80	592
Right side of the back deck (at floor level)	271	307
Left side of the back deck (at floor level)	570	1290*
Middle of the back deck	140	774
On stairs going up to top deck	63	335

Generator and Motors Running (ran together for approximately 21 minutes)		
On the top deck of boat	17	19
Inside the boat	16	76

*The CO peaks reflect the highest concentration that these sensors can record. The actual peak concentration may have exceeded these values.

59' Fun Country Houseboat

During the afternoon on January 23, 2001, CO samples were collected on a 59' houseboat with the specifications listed below. This houseboat was equipped with a gasoline generator and motors. The generator was operated for approximately 45 minutes. The motors would not start during this evaluation; therefore, only generator data is presented.

Generator: 12.5 Kw Kohler, 1.3 liter - 4 cylinder gasoline generator
Exhaust Configuration: Generator exhausted out the back of the boat on the left side (when on the back of the boat and facing the water) near the slide.
Air speed above deck: air speed readings ranged between 106 - 215 feet per minute on the back deck
Air speed off back of back deck (near water): air speed readings ranged between 16 - 101 feet per minute

Area around exhaust off back of houseboat and beneath swim deck

An evacuated glass container sample collected near the bottom of the slide, above where the generator exhaust is located, indicated a CO concentration of 1,354 ppm. Another evacuated container sample was collected near the ladder off the back of the houseboat that leads into the water. This sample was collected approximately 12 inches above the water and indicated a CO concentration of 648 ppm. An evacuated container collected in the middle of the back deck at breathing zone height during the evaluation indicated a CO concentration of 1 ppm. A detector tube collected near the exhaust area off the back of the boat indicated a CO concentration of 3,000 ppm.

The emissions analyzer sampling probe was placed in the area directly near the generator exhaust discharge. A total of 14 readings were obtained when the generator was in operation. The recorded CO concentration ranged from 0.07 % (700 ppm) to 0.98 % (9,800 ppm) with an average of 0.43 % (4,300 ppm). During brief periods, when the CO concentrations were high, the emissions analyzer also indicated that the area directly around the exhaust discharge was oxygen deficient (< 19.5 % O_2).

Area Above Swim Deck on Back of Boat

The wind velocity ranged between 106 - 215 fpm on the back deck of the houseboat. The prevailing wind direction was from the right side of the back deck (when on back of boat and facing the water) and flowing across the back deck toward the left side of the boat. Table 3 list the CO monitor results.

Table 3. Sample locations and CO results on the 59' Fun Country houseboat.

Location	CO average (ppm)	CO peak (ppm)
Only Generator Running (approximately 45 minutes)		
On the back of the slide at breathing zone height	20	135
On stairs going up to top deck	17	132
Left side of back deck (at floor level)	124	1074
Right side of back deck (at floor level)	17	310
Center of back deck (at floor level)	152	1197
On the top deck of boat	12	53
On the left side of the rear portion of the back deck	27	156
On the right side of the rear portion of the back deck	26	226
Inside the boat	9	27

65' Houseboat (2000 Model)

During the afternoon on January 23, 2001, area CO samples were collected on a 2000 model 65' houseboat with the specifications listed below. This houseboat was taken out to a cove on the lake to collect CO data. The houseboat was equipped with a gasoline generator and motors. During this evaluation, the gasoline generator operated alone for approximately 36 minutes. Subsequently, the gasoline motors and generator were operated together for approximately 17 minutes.

Engine: 2 outboard, 175 HP, Evinrude Ficht® engines
Generator: 20.0 Kw Kohler, 4 cylinder gasoline generator
Exhaust Configuration: Generator exhaust was exhausted out the back right (when on the boat and facing the water) portion of the boat.

Air speed above deck: air speed readings ranged between 168 - 244 feet per minute

Air speed below deck: air speed readings ranged between 8 - 91 feet per minute

Area around back of houseboat and beneath swim deck

Two evacuated glass container samples were collected at the back of the houseboat (near the stairs which go down into the water). These samples indicated CO concentrations of 883 ppm and 1385 ppm when only the generator was in operation. Two detector tubes were collected in the area off the back of the houseboat at two separate time periods when only the generator was in operation. These samples indicated CO concentrations of approximately 3,000 ppm and 700 ppm. Another evacuated container sample was collected off the back of the houseboat near the slide when the generators and motors were in operation. This sample indicated a CO concentration of 390 ppm.

The emissions analyzer sampling probe was placed in the area directly near the generator exhaust discharge. A total of 10 readings were obtained when the generator was in operation. The recorded CO concentration ranged from 0.0 % to 0.37 % (3,700 ppm) with an average of 0.17 % (1,700 ppm). A total of 5 readings were obtained when the generator and motors were in operation. The recorded CO concentration (obtained near the exhaust discharge) ranged from 0.01 % (100 ppm) to 0.44 % (4,400 ppm) with an average of 0.27 % (2,700 ppm).

Area Above Swim Deck on Back of Boat

Table 4 lists the CO monitor results obtained on the back of the 65' houseboat (2000 model) houseboat. The prevailing wind direction was from the right front side of the back deck (when on back of boat and facing the water) and flowing across the back deck toward the left back side of the back deck.

Table 4. Sample locations and CO results on the 65' houseboat (2000 model) out in the cove.

Location	**CO average (ppm)**	**CO peak (ppm)**
Only Generator Running (ran for approximately 36 minutes without motors operating)		
On the back of the slide at breathing zone height	2	19
On stairs going up to top deck	0.8	4
Left side of back deck (at floor level)	139	450
Right side of back deck (at floor level)	2.3	20
Center of back deck (at floor level)	416	788
On the top deck of boat	0.23	3

Only Generator Running (ran for approximately 36 minutes without motors operating)		
On the left side of the rear portion of the back deck	2	14
On the right side of the rear portion of the back deck	0.9	5
Generator and Motors Running (ran together for approximately 17 minutes)		
On the back of the slide at breathing zone height	0.2	1
On stairs going up to top deck	0.15	1
Left side of back deck (at floor level)	31	128
Right side of back deck (at floor level)	25	131
Center of back deck (at floor level)	108	319
On the top deck of boat	non-detected	non-detected
On the left side of the rear portion of the back deck	non-detected	non-detected
On the right side of the rear portion of the back deck	0.05	2

56' Fun Country Houseboat

During the morning on January 24, 2001, CO samples were collected on a 56' houseboat with the specifications listed below. The houseboat was placed in a cove on the lake during the evaluation. The houseboat was equipped with a gasoline generator and motors. During this evaluation, the gasoline generator operated alone for approximately 35 minutes. Subsequently, the gasoline motors and generator were operated together for approximately 21 minutes.

Engines: Two 130 HP, I/O, 4 cylinder Volvo engines
Generator: 12.5 Kw Kohler, 1.3 liter - 4 cylinder gasoline generator
Exhaust Configuration: Generator exhausted out the back of the boat.
Air speed above deck: air speed readings ranged between 10 - 80 feet per minute on the back deck
Air speed off back of back deck (near water): air speed readings ranged between 4 - 52 feet per minute

Area around exhaust off back of houseboat and beneath swim deck

An evacuated glass container sample was collected near the center of the swim platform approximately 10 inches above the water. This sample indicated a CO concentration of 1,069 ppm. A detector tube (range of 0- 700 ppm) collected in this area was saturated (CO concentrations > 700 ppm). Another detector tube sample was collected on a tube with a higher range (3,000 - 70,000 ppm) and indicated a color change just below the 3,000 ppm indicator line. Therefore, it is probable that the CO concentration indicated by the detector tubes was between 700 - 3,000 ppm in the area near the center of the swim platform approximately 10 inches above the water. An evacuated container sample was collected (approximately 14 minutes after the first evacuated container sample) near the ladder that leads into the water off the back deck. This sample did not detect CO.

An evacuated container sample collected near the center of the swim platform (approximately 10 inches above the water) when the generator and engines were operating simultaneously indicated a CO concentration of 4,404 ppm.

The emissions analyzer sampling probe was placed off the back of the rear deck in the area near the generator exhaust discharge. A total of 9 readings were obtained when the generator was in operation, exclusively. The recorded CO concentrations ranged from 0.16 % (1,600 ppm) to 0.84 % (8,400 ppm) with an average of 0.39 % (3,900 ppm).

A total of 8 readings were obtained when the generator and motors were in operation simultaneously. The recorded CO concentrations (obtained near the generator exhaust discharge off the back of the boat) ranged from 0.19 % (1,900 ppm) to 0.82 % (8,200 ppm) with an average of 0.52 % (5,200 ppm) while the generator and engines were in operation. During brief periods, when the CO concentrations were high (while the motors and generator were in operation), the emissions analyzer would also indicate that the area around the exhaust discharge was oxygen deficient (< 19.5 % O_2).

Area Above Swim Deck on Back of Boat

Table 5 lists the CO monitor results obtained on the back of the 56' Fun Country houseboat while the boat was stationary in a cove on the lake. The wind velocity ranged between 10 - 80 fpm and was moving in different directions on the back of the houseboat during the testing period.

Table 5. Sample locations and CO results on the 59' Fun Country houseboat.

Location	CO average (ppm)	CO peak (ppm)
Only Generator Running (ran for approximately 35 minutes without motors operating)		
On the back of the slide at breathing zone height	13	184
On stairs going up to top deck	39	210
Right side of swim platform (at floor level)	203	797
On the top deck of boat	18	76
On the left side of the rear portion of the back deck	32	224
On the right side of the rear portion of the back deck	53	222
Generator and Motors Running (ran together for approximately 21 minutes)		
On the back of the slide at breathing zone height	49	158
On stairs going up to top deck	98	366
Right side of swim platform (at floor level)	427	1045
On the top deck of boat	37	154
On the left side of the rear portion of the back deck	113	319
On the right side of the rear portion of the back deck	144	658

67' VIP Houseboat

During the morning on January 24, 2001, the 67' VIP houseboat was placed out in a cove on the lake to evaluate CO concentrations (see Figure 3). This is the same houseboat that was evaluated at the dock on the fist day of the evaluation. During this evaluation, the gasoline generator operated alone for approximately 60 minutes. Subsequently, the gasoline motors and generator were operated together for approximately 10 minutes. The 67' VIP houseboat had the following specifications.

Engines: Two Evinrude Ficht® outboard marine corporation (OMC), 150 HP, engines
Generator: 15 Kw Kohler, 4 cylinder, 1800 RPM, gasoline generator
Exhaust Configuration: Generator exhaust discharged out to the side of the houseboat.

Air speed above deck: air speed readings ranged between 38 - 170 feet per minute
Air speed at side of deck near generator exhaust: air speed readings ranged between 21 - 135 feet per minute

Area around exhaust off back of houseboat and beneath swim deck

An evacuated glass container sample collected near the left side (when on the back of the boat and facing the water) of the swim platform off the back of the boat indicated a CO concentration of 20 ppm. Two evacuated container samples were collected directly off the back of the boat at the stairs that lead down to the water at different times during the evaluation while the generator was in operation, exclusively. These samples indicated CO concentrations of 201 and 2,240 ppm. A detector tube collected in this area indicated a CO concentration of 3,000 ppm when the generator was in operation.

The emissions analyzer sampling probe was placed off the back of the rear deck in the area near the generator exhaust discharge. A total of 12 readings were obtained when the generator was in operation, exclusively. The recorded CO concentrations ranged from 0.09 % (900 ppm) to 1.92% (19,200 ppm) with an average of 0.74 % (7,400 ppm). Two readings were obtained when the generator and motors were in operation simultaneously and indicated CO concentrations of 0.24 % (2,400 ppm) and 1.4 % (14,000 ppm). During brief periods, when the CO concentrations were high, the emissions analyzer would also indicate that the area around the exhaust discharge was oxygen deficient (< 19.5 % O_2).

Area Above Swim Deck on Back of Boat

Table 6 lists the CO monitor results obtained on the back of the 67' VIP houseboat while the boat was stationary in a cove on the lake. The wind velocity ranged between 38 - 170 fpm and the prevailing movement was from the left side of the back deck (while on the back of the boat and facing the water) toward the right side of the back deck.

Table 6. Sample locations and CO results on the 67' VIP houseboat in a cove on the lake.

Location	**CO average (ppm)**	**CO peak (ppm)**
Only Generator Running (ran for approximately 60 minutes without motors operating)		
On the back of the slide at breathing zone height	59	668
On stairs going up to top deck	52	365
Right side of back deck (at floor level)	177	505
Left side of back deck (at floor level)	298	1294*
Center of back deck (at floor level) near stairs entering the water	340	1195*
On the top deck of boat	41	402

Only Generator Running (ran for approximately 60 minutes without motors operating)		
On the left side of the rear portion of the back deck	120	826
On the right side of the rear portion of the back deck	61	317
Generator and Motors Running (ran together for approximately 10 minutes)		
On the back of the slide at breathing zone height	24	53
On stairs going up to top deck	24	57
Right side of back deck (at floor level)	50	144
Left side of back deck (at floor level)	86	199
Center of back deck (at floor level) near stairs entering the water	184	644
On the top deck of boat	13	23
On the left side of the rear portion of the back deck	54	159
On the right side of the rear portion of the back deck	22	62

*The CO peaks reflect the highest concentration that these sensors can record. The actual peak concentration may have exceeded these values.

Discussion and Recommendations

The Fun Country Marine houseboats evaluated at Callville Marina were designed with a solid hull and did not have any enclosed spaces beneath the back deck. With this type of design the CO levels could not build up in an enclosed space beneath the back deck as seen on previous evaluations.[1,2,3] During this evaluation, CO concentrations near the exhaust (measured with the emissions analyzer) would dissipate quickly (within a few minutes) after the generator/engines were turned off. However, when gasoline generators were in operation, extremely high CO concentrations (above IDLH levels) were measured near the generator exhaust. High CO concentrations (occasionally measured above IDLH) were also measured around the back deck (near water level), on houseboats that exhaust the generator combustion gases out the back. These hazardous conditions also exist when the engines are in operation on the boats.

During this survey, only one of the houseboats exhausted the generator to the side of the boat hull (see Figures 2 and 3). The area around the exhaust on the side of the boat indicated CO concentrations above the NIOSH IDLH value of 1,200 ppm[4] when measured at the dock and in a cove on the lake. CO concentrations around the back deck (approximately 6-12 inches above the water where individuals could conceivably be swimming) indicated high CO concentrations (896 ppm) while the

boat was at the dock, and while stationary in a cove on the lake, CO concentrations were measured above the NIOSH IDLH value. In the cove, high CO concentrations (>1000 ppm) were also measured on the floor of the back deck while the generator was in operation.

This investigation documents the potential for CO exposure on houseboats that utilize gasoline generators that exhaust out the back or the side near water level. Individuals swimming or working in the area directly near the exhaust or behind the back deck (with the gasoline generator in operation) could be exposed to extremely high CO concentrations resulting in CO poisoning or death within a short period of time. The area on the back deck of houseboats is also a concern. When the generator or motors are in operation, the area around the back deck of houseboats can be hazardous under certain conditions, particularly when there is little air movement.[1]

This evaluation was performed in January which is not in the prime operating season for houseboats. Activities at the dock were slow, due to the low number of houseboat rentals. Therefore, personal sampling was not conducted. However, general recommendations are provided to help control potential worker CO exposures. In addition, recommendations are provided to reduce the potential for CO exposure around the generator exhaust and back deck on houseboats.

1) Public education efforts must immediately inform and warn all individuals (including boat owners, renters, and dock workers) potentially exposed to these CO hazards. Public education programs should continue until engineering control solutions that eliminate the problem are in place.

An effort is being made to inform manufacturers of houseboats about the environmental data that has been collected, and the related design concerns. On September 1, 2000, the National Park Service (NPS) sent each of these manufacturers a letter informing them of the numerous deaths that may be attributed to CO poisoning from houseboat generator and/or engine exhaust. In these letters, the Park Service specifically pointed out that most of the deaths occurred when the victim was either on the back deck or in the water near or under the swim platform. In addition to this effort, the initial NIOSH letter describing the first evaluation of CO on houseboats at Lake Powell was also sent to 58 houseboat manufacturers.[1] This effort should be continued until all manufacturers are aware of the problem and solutions are formulated to redesign and correct the exhaust configuration. This should also include the redesigning of side-exhausting boats to help eliminate CO problems when boats are tied together, or when someone is in the area where the exhaust gases are expelled from the boat. An investigation was conducted at Lake Powell on a houseboat with a generator exhaust design that discharged the exhaust gases through a stack well above the upper deck of the houseboat. This study indicates that the exhaust gases can diffuse and dissipate into the atmosphere to relatively safe levels, prior to reaching occupants on or near the houseboat.[5]

2) Previous investigations have indicated that boat mechanics can be exposed to high concentrations of CO.[1,2] Therefore, the feasibility and effectiveness of engineering controls should be investigated to help control CO exposures to boat maintenance mechanics. If repairs are conducted outside and at the

boat dock (where electric power is easily available), the use of a high volume fan or other air-moving device may be effective in preventing worker short-term high-level exposures to CO. Research into potential engineering controls needs to be accomplished to make sure that the workers' breathing zone is protected from CO and that any exhaust from these controls is discharged into a well-ventilated area that is not occupied; therefore, eliminating the possibility of individuals breathing the exhaust from the control device.

3) Training about the severity of CO hazards in boating should be developed for marina personnel, EMS providers, and hospital emergency department staff so that symptoms experienced by either employees or other boat operators might be more easily associated with exposures. This training should include both environmental data, as well as information about the number and circumstances of CO poisonings on the lake.

4) The U.S. NPS has launched an awareness campaign to inform boaters on Lake Powell about boat-related CO hazards. This alert included press releases, flyers distributed to boat and dock-space renters, and verbal information included in the boat check-out training provided for users of concessionaire rental boats. Similar information should be distributed to boat and dock-space renters at Callville Marina. Verbal information should be included in the boat check-out training provided for users of rental boats. Training about the specific boat-related CO hazards provided to houseboat renters, should include specific information about the circumstances and number of poisonings and deaths that have been documented in previous CO evaluations.[1] The training should include anecdotal information about deaths and near misses, and should specifically target warnings against entering areas near the gasoline generator exhaust or immediately behind the back deck that may contain a lethal atmosphere.

Thank you for your cooperation with this investigation, and for providing important data related to this serious issue. Please contact me at (513) 841-4387 if you have any questions regarding this evaluation. Jane McCammon at (303) 236-6233 is an additional contact who can answer any questions or concerns you may have regarding CO fatalities and poisoning incident reports on houseboats.

Sincerely,

Ronald M. Hall, M.S.
Industrial Hygienist
Industrial Hygiene Section
Hazard Evaluations and Technical Assistance Branch
Division of Surveillance, Hazard Evaluations and Field Studies

cc: Dick Powell, USNPS Safety Director
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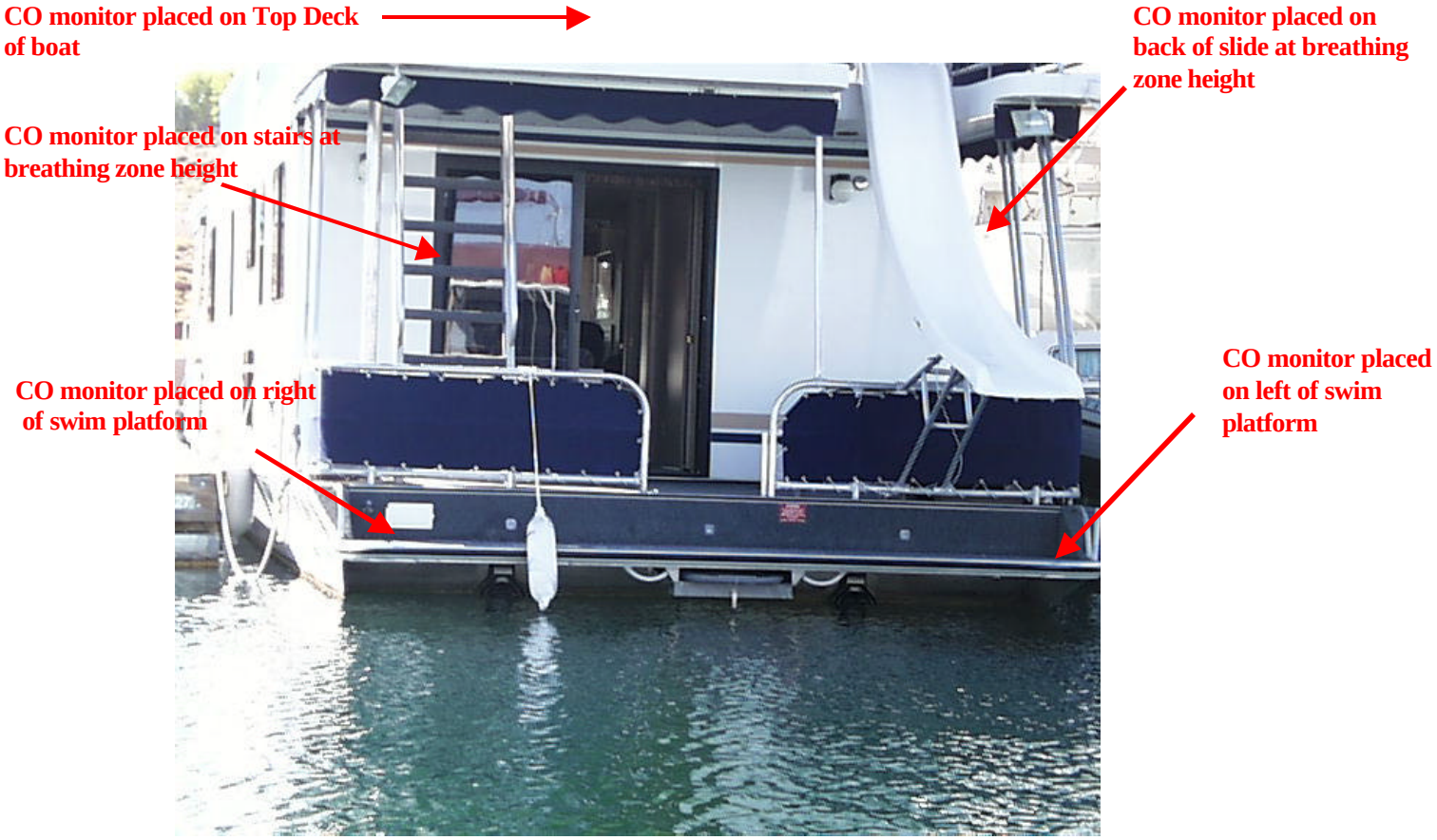

Figure 1. Swim platform and back deck of a houseboat with general CO sample locations. [This figure indicates the general locations of CO monitors during all houseboats evaluations and may not be representative of a typical houseboat at Callville Marina.]

Figure 2. Generator side exhaust on the 67' VIP houseboat at the dock.

Figure 3. Generator exhaust discharge on the 67' VIP Houseboat in a cove on the lake.

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Attachment 1
Health Effects of Exposure to Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless, tasteless gas produced by incomplete burning of carbon-containing materials such as gasoline or propane fuel. The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, or nausea. Symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. If the exposure level is high, loss of consciousness may occur without other symptoms. Coma or death may occur if high exposures continue.[1-6] The display of symptoms varies widely from individual to individual, and may occur sooner in susceptible individuals such as young or aged people, people with preexisting lung or heart disease, or those living at high altitudes.

Exposure to CO limits the ability of the blood to carry oxygen to the tissues by binding with the hemoglobin to form carboxyhemoglobin (COHb). Blood has an estimated 210-250 times greater affinity for CO than oxygen, thus the presence of CO in the blood can interfere with oxygen uptake and delivery to the body. Once absorbed into the bloodstream, the half-life of bloodborne CO at sea level and standard pressure is approximately five hours. This means that an initial COHb level of 10% could be expected to drop to 5% in five hours, and then 2.5% in another five hours. If oxygen is administered to the exposed person, as happens in emergency treatment, the COHb concentration drops more quickly. Once exposed, the body compensates for the reduced bloodborne oxygen by increasing cardiac output, thereby increasing blood flow to specific oxygen-demanding organs such as the brain and heart. This ability may be limited by preexisting heart or lung diseases that inhibit increased cardiac output.

Altitude effects the toxicity of CO. With 50 ppm CO in the air, the COHb level in the blood is approximately 1% higher at an altitude of 4,000 feet than at sea level. This occurs because the partial pressure of oxygen (the gas pressure causing the oxygen to pass into the blood) at higher altitudes is less than the partial pressure of CO. Furthermore, the effects of CO poisoning at higher altitudes are more pronounced. For example, at an altitude of 14,000 feet, a 3% COHb level in the blood has the same effect as a 20% COHb at sea level.[7]

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Attachment 2
Evaluation Criteria

Although NIOSH typically focuses on occupational safety and health issues, the Institute is a public health agency, and cannot ignore the overlapping exposure concerns in this type of setting. Lake Mead employees should be in a state of health typical of any industrial worker. Thus, occupational criteria for CO exposure are applicable to that group. The general boating public, however, may range from infant to aged, be in various states of health and susceptibility, and be functioning at a higher rate of metabolism because of increased physical activity. The effects of CO are more pronounced in a shorter time if the person is physically active, very young, very old, or has preexisting health conditions such as lung or heart disease. Persons at extremes of age and persons with underlying health conditions may have marked symptoms and may suffer serious complications at lower levels of carboxyhemoglobin.[(1)] The occupational exposure limits noted below should not be used for interpreting general population exposures because they would not provide the same degree of protection they do for the healthy worker population.

Occupational Exposure Criteria. As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, or a pre-existing medical condition. In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[(2)] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®), [(3)] (3) the legal requirements of the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs),[(4)] and (4) the American Society of Heating, Refrigerating, and Air-ConditioningEngineers (ASHRAE) Standard for ventilation for acceptable indoor air quality.[(5)] Employers are encouraged to follow the more protective criterion listed.

A TWA exposure refers to the average airborne concentration of a substance during a normal 8-to-10-hour workday. Some substances have recommended short-term exposure limits (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

The NIOSH REL for CO is 35 ppm for full shift TWA exposure, with a ceiling limit of 200 ppm which should never be exceeded.[6,7] The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5%.[1] NIOSH has established the immediately dangerous to life and health (IDLH) value for CO as 1,200 ppm.[8] An IDLH value is defined as a concentration at which an immediate or delayed threat to life exists or that would interfere with an individual's ability to escape unaided from a space.

The ACGIH recommends an eight-hour TWA TLV of 25 ppm based upon limiting shifts in COHb levels to less than 3.5%, thus minimizing adverse neurobehavioral changes such as headache, dizziness, etc, and to maintain cardiovascular exercise capacity.[9]

The OSHA PEL for CO is 50 ppm for an 8-hour TWA exposure.[10]

Health Criteria Relevant to the General Public.
The US EPA has promulgated a National Ambient Air Quality Standard (NAAQS) for CO. This standard requires that ambient air contain no more than 9 ppm CO for an 8-hour TWA, and 35 ppm for a one-hour average.[11] The NAAQs for CO was established to protect "the most sensitive members of the general population" by maintaining increases in carboxyhemoglobin to less than 2.1%.

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Toxicity Det: High concentrations of Carbon Monoxide